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AERONAUTIC & ORDNANCE SYSTEMS DEPARTMENT

GENERAL ELECTRIC COMPANY

SCHENECTADY, NEW YORK

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ENGINEERING PROGRESS REPORT NO. 21

ON

DEVELOPMENT PROGRAM FOR AN AUTOMATIC PILOT FOR HIGH PERFORMANCE AIRCRAFT

GET-2257-13

Period Covered
12/24/52 to 1/24/53

Submitted
8/4/53

FOR

UNITED STATES AIR FORCE
AIR MATERIEL COMMAND
WRIGHT-PATTERSON FIELD

CONFIDENTIAL

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FOREWORD

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SECTION I

PURPOSE

The purpose of this project is: (a). To study, design, and build a flyable, breadboard model of an automatic pilot which will provide stable, positive, automatic control of bombardment, transport, cargo and fighter-type aircraft from landing speeds through the sonic range, and up to speeds anticipated for aircraft that will be flying through 1956.

SECTION II

GENERAL FACTUAL DATA

A. A total of 95936 engineering and drafting man hours have been devoted to this project to date.

B.

1. Development and construction of components suitable for flight testing the fighter type autopilot has been completed.

2. Completion of components construction suitable for flight testing the bomber type autopilot has been delayed by extension of the fighter autopilot flight test program beyond the date originally anticipated.

C. No manufacturing difficulties were encountered during this period.

D. The assistance of the project engineer is required to resolve the matter of additional funds to provide engineering service for the F-94 and B-47 flight test programs.

E. No patent dockets were filed during this period.

F. Field trips made during this period:

SECTION III

SYSTEM DEVELOPMENT

INTRODUCTION

This progress report covers the one-month period from 12/24/52 through 1/24/53. Progress report No. 20 reported on the work done during the period from 9/24/52 through 12/24/52. The period covered by report No. 20 was three months instead of the normal two in order that the complete F-94 flight test program conducted in Schenectady would be covered in one report.

A. BOMBER AUTOPILOT

1. General

A trip was made to Boeing, Wichita, during this period to obtain autopilot installation information and to discuss, in general, autopilot problems associated with the B-47.

This meeting brought out a number of the following potential problems which may arise in the MX1137 installation.

a. Aileron Wallow.

There may be need for minimizing slop in the aileron control cables, particularly if the aileron servo is located far from the aileron power control system.

b. Static Pressure Measurement.

Variations in static pressure, due to changes in airplane configuration (i.e., lowering flaps, opening bomb doors, etc.), may make barometric altitude control a problem.

c. Gain Changing.

The need for gain changing is particularly apparent in pitch control. Instability may appear in the form of either:

(1) a long period phugoid oscillation; or

(2) a short period (2 seconds/cycle)porpoising.

During the next period the airplane - autopilot stability problem will be analyzed utilizing the analog computer for simulation of the airplane dynamic response characteristics.

B. FIGHTER AUTOPILOT

1. F-94 Flight Test Program

The F-94 is now undergoing a transfer inspection prior to being returned to Wright Field for instrumentation and completion of Phase III flight tests.

The overall objective of the Phase III program is primarily to evaluate the basic fighter autopilot system developed on the MX1137 contract. A secondary objective is to conduct more advanced autopilot system flight tests consistent with the desires of both WADC and the General Electric Company to supplement the basic program with the results of development work being carried on now.

The following is an outline of the general objectives of the MX1137 fighter autopilot flight test program to be conducted at WADC.

I. BASIC AUTOPILOT SYSTEM EVALUATION

A. Longitudinal Control

1. Pitch Damping System (Parallel - connected)
2. Altitude - Altitude rate system
   a. Level Flight Stability
   b. Rate-Type Pitch Maneuvering
3. Altitude - Vertical gyro system
   a. Level Flight Stability
   b. Position - Type Pitch Maneuvering

4. Indicated Airspeed Control
   a. Airspeed - Airspeed rate control through elevators
   b. Airspeed - Airspeed rate control through throttles
5. Simultaneous Altitude and Airspeed Control
   a. Altitude through Elevators; Airspeed through throttles
   b. Altitude through throttles; Airspeed through elevators
   c. Blending Controls
6. Cruise Control (Constant Mach number control through the elevators)
7. Flight Path Control
   a. Glide Path Tie-in to Elevator Channel
   b. Airspeed Tie-in to Throttle Channel
8. Elevator Trim Tab Control
9. Safety Features:
   a. G-Limiting
   b. G-Plus G-Rate Cutout of Autopilot in the Event of Signal System Failure
   c. Synchronization Interlock
10. Force Switch Maneuvering in Pitch

B. <u>Lateral Control</u>

1. Yaw Damping and Coordination Control
   a. Pendulum Reference System
   b. Yaw Vane Reference System
   c. Lateral Accelerometer Reference System
2. Directional Gyro - Yaw Rate - Roll Rate System
   a. Level Flight Heading Control Stability
   b. Rate-Type Roll Maneuvering:
      (1) Without altitude control
      (2) With altitude control - turn compensation provided by:
         (a) Pitch rate cancelling
         (b) Computed bias signal

3. Flight Path Control
   a. Beam Guidance Tie-in
      (1) Omnirange
      (2) Localizer
   b. Simulated Interceptor Fire Control Tie-in
   c. Magnetic Heading Selection
4. Force Switch Roll Maneuvering

The above items are considered to be the basic autopilot functions which should be investigated during the course of the F-94 flight test program. In addition to this work, other system features and configurations may be flight tested if desirable and if sufficient time is available.

2. <u>F-94 Analysis</u>

Analysis of the airplane - autopilot combination in the F-94 has been based upon the four flight conditions tabulated in Table I. The longitudinal and lateral equations of motion for these conditions are also included in Tables II and III.

In addition to these four conditions, simplified transfer functions for a fifth flight condition (most representative of the flight conditions used during the 12-hour F-94 flight test program in Schenectady) have been derived.

TABLE I

F-94 FLIGHT CONDITIONS

S = Wing Area = 238 sq. ft.
b = Wing Span = 38.88 ft.
$\bar{c}$ = Mean Aerodynamic Chord = 6.72 ft.

Condition No.

	1	2	3	4
Description	Landing	Cruising	Abnormal Config.	Top Speed
h (ft)	S. L.	35000	S. L.	S. L.
V (TAS, mph)	135	450	553	606
M	0.18	0.69	0.727	0.8
W (lb)	12359	13614	16091	13614
ρ (plugs/ft^3)	2.378×10^{-3}	7.37×10^{-4}	2.38×10^{-3}	2.38×10^{-3}
V (ft/sec)	198	660	811	889
q (lbs/ft^2)	46.6	160	780	940
m (slugs)	384	423	500	423
α (degrees)	+6	+2.7	-0.25	-0.5
C_L	1.11	0.36	0.09	0.06

TABLE II

F-94 LONGITUDINAL EQUATIONS

Flight Condition No.	
	Drag Equations
1	$pu' = -0.0628\ u' - 0.162\ \theta + 0.073\alpha$
2	$pu' = -0.038\ u' - 0.0494\ \theta + 0.0206\alpha$
3	$pu' = -0.0386\ u' - 0.0413\ \theta + 0.0178\alpha$
4	$pu' = -0.182\ u' - 0.0357\ \theta + 0.0184\alpha$
	Lift Equations
1	$p\alpha = 0.0992\ p\theta - 0.331\ u' - 0.77\ \alpha - 0.0543\ \delta_e$
2	$p\alpha = 1\ p\theta - 0.140\ u' - 0.723\ \alpha - 0.0590\ \delta_e$
3	$p\alpha = 1\ p\theta - 0.124\ u' - 2.42\ \alpha - 0.197\ \delta_e$
4	$p\alpha = 1\ p\theta - 0.135\ u' - 3.12\ \alpha - 0.256\ \delta_e$
	Pitching Moment
1	$p^2\theta = -0.370\ p\theta - 0.194\ p\alpha - 1.14\alpha - 0.00297\ u' - 2.63\ \delta_e$
2	$p^2\theta = -0.394\ p\theta - 0.207\ p\alpha - 4.24\ \alpha - 0.245\ u' - 9.1\ \delta_e$
3	$p^2\theta = -1.545\ p\theta - 0.809\ p\alpha - 20.6\ \alpha - 0.334\ u' - 44.2\ \delta_e$
4	$p^2\theta = -1.72\ p\theta - 0.900\ p\alpha - 24.9\ \alpha - 0.494\ u' - 53.4\ \delta_e$

These equations have been set up and analyzed on the analog computers and it is planned to re-check this analysis using the WADC computers during the course of the flight test program at Wright Field.

TABLE III

F-94 LATERAL EQUATIONS

NOTE: Conditions 1, 2, and 4 have tip tanks included. Assumed weight/tank = 300 lbs.

Flight Condition No.	Equation	
1	$p^2\Phi = -1.57\,p\Phi - 0.211\,p^2\psi + 0.976\,p\psi - 1.74\,\beta - 1.64\,\delta_a + 0.204\,\delta_r$	Roll Equations
2	$p^2\Phi = -0.92\,p\Phi - 0.036\,p^2\psi + 0.262\,p\psi - 5.27\,\beta - 4.58\,\delta_a + 0.455\,\delta_r$	
3	$p^2\Phi = -1.75\,p\Phi + 0.011\,p^2\psi + 0.206\,p\psi - 13.35\,\beta - 8.92\,\delta_a + 1.06\,\delta_r$	
4	$p^2\Phi = -3.98\,p\Phi + 0.018\,p^2\psi + 0.421\,p\psi - 31.0\,\beta - 30.2\,\delta_a + 2.67\,\delta_r$	
1	$p^2\psi = -0.0204\,p\psi - 0.0601\,p^2\Phi + 0.0051\,p\Phi + 1.11\,\beta - 0.702\,\delta_r + 0.0358\,\delta_a$	Yaw Equations
2	$p^2\psi = -0.0125\,p\psi - 0.0142\,p^2\Phi + 0.00094\,p\Phi + 3.62\,\beta - 2.16\,\delta_r + 0.135\,\delta_a$	
3	$p^2\psi = -0.334\,p\psi + 0.0066\,p^2\Phi + 0.059\,p\Phi + 9.9\,\beta - 7.65\,\delta_r + 0.311\,\delta_a$	
4	$p^2\psi = -0.566\,p\psi + 0.00704\,p^2\Phi + 0.097\,p\Phi + 19.65\,\beta - 13.45\,\delta_r + 0.547\,\delta_a$	
1	$p\beta = -p\psi + 0.162\,\Phi - 0.126\,\beta + 0.0218\,\delta_r$	Sideslip Equations
2	$p\beta = -p\psi + 0.0494\,\Phi - 0.0762\,\beta + 0.0204\,\delta_r$	
3	$p\beta = -p\psi + 0.0413\,\Phi - 0.247\,\beta + 0.0684\,\delta_r$	
4	$p\beta = p\psi + 0.0357\,\Phi - 0.321\,\beta + 0.0887\,\delta_r$	

These equations have been set up and analyzed on the analog computers and it is planned to re-check this analysis using the WADC computers during the course of the flight test program at Wright Field.

3. Trim Tab Control Circuit Development

During this period a control circuit was developed for the F-94 elevator trim tab actuator. Operating in conjunction with the basic auto-pilot servo actuator in the elevator channel, this control circuit provides automatic elevator trim tab control.

The circuit developed to perform this function is shown in Figure 1. The trim tab control consists of a balanced armature relay which monitors any unbalance in the basic servo motor currents and which runs the trim tab actuator when this unbalance is too great. For proper trim this circuit is made sensitive to very small unbalance in motor currents.

High sensitivity has the disadvantage that the relay will pick up and chatter when the servo motor is tracking a signal. Normally this would mean that the trim tab actuator would be continuously started and stopped, resulting in shorter life both for it and for the relay contacts supplying its power.

The circuit shown in Figure 1 eliminates this disadvantage by delaying pick up of the trim tab actuator control relay. In addition, the drop out of this relay is instantaneous, thereby preventing the actuator from over-shooting its proper position.

The actuator now is required to run only for a sustained signal and stops immediately when this signal is satisfied. This circuit will be installed in the F-94 during the next period for flight test evaluation.

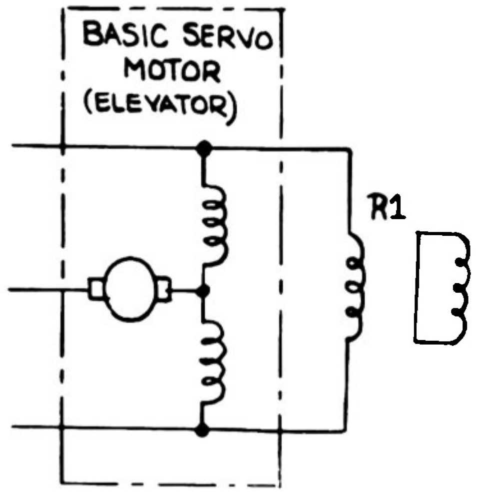
SECTION IV
COMPONENT DEVELOPMENT

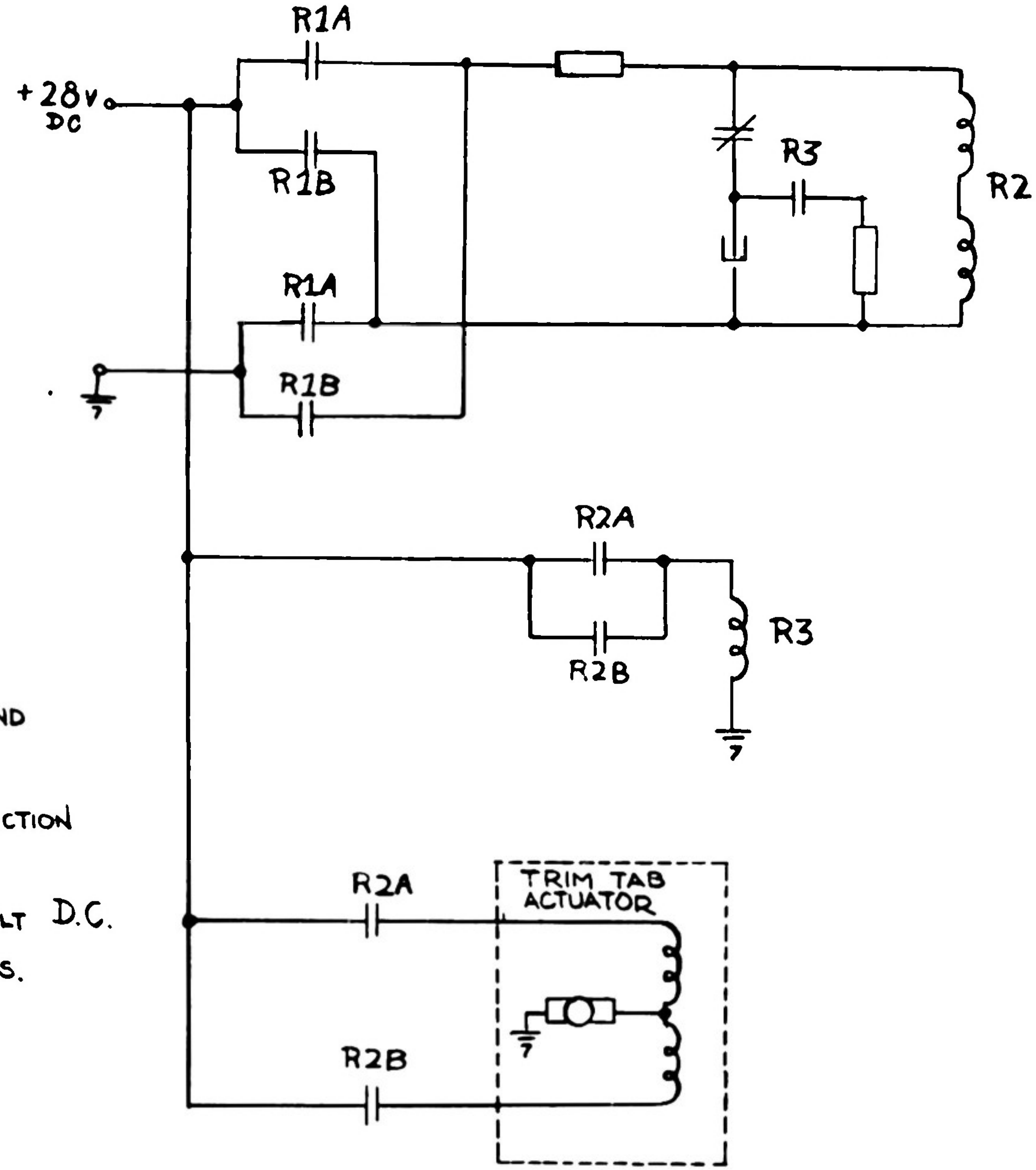
A. MAGNETIC AMPLIFIERS

Development effort during this month has been concentrated on the half-wave magnetic amplifier replacement for the basic servo amplifiers now installed in the F-94.

Half-wave magnetic amplifier controls for the synchronizing drive and the solenoid - operated hydraulic valve are also being developed.

Details of these circuits will be included in later reports as development progresses.





NOTE :

1. R 1 AND R 2 ARE BALANCED ARMATURE TYPE RELAYS.
2. CONTACT DESIGNATIONS "A" AND "B" INDICATE CONTACTS WHICH CLOSE TOGETHER FOR EACH DIRECTION OF RELAY PICK-UP.
3. R 3 IS A STANDARD 28 VOLT D.C. RELAY WITH FORM - C CONTACTS.

FIG. 1

TRIM TAB CONTROL CIRCUIT